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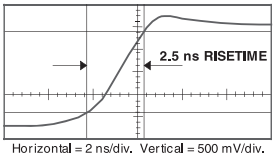
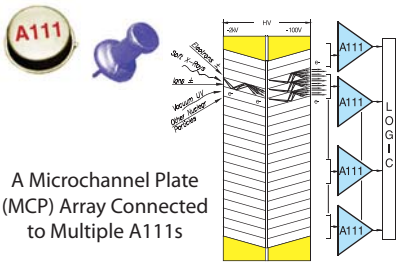


Horizontal = 2 ns/div. Vertical = 500 mV/div.

THE INDUSTRY STANDARD
A111



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characteristic length scales: a persistence length of order 1 nm, which represents the step size in the chain orientation's random walk; an overall radius of gyration, of order 10–100 nm, a measure of the polymer's average size; and an intermediate entanglement length scale, of order 5–10 nm, that dictates many aspects of the viscoelastic and flow properties of molten polymers. Similarly, when such a polymer crystallizes, the unit cell has dimensions of order 1 nm; the lamellar thickness, 10–100 nm; and the bulk spherulites, microns to millimeters. The two longer length scales are determined by processing and are therefore usually under kinetic control. Whether bioinspired or not, the ability to control structure on multiple length scales in a rational way represents an emerging intellectual frontier in polymer science.

Collaborators needed

The NSF report highlights the urgent need for new partnerships and modes of collaboration among industry, academia, and national laboratories. The constriction of industrial resources for long-term research means that industry has to rely on intellectual engagement with universities and national labs as never before. On the other hand, the intense competition for federal research funds suggests that academics in particular could benefit from deeper relations with company scientists and engineers, especially if new intellectual-property models can be implemented.

While *The Graduate* and *Macromolecules* are each marking their 50th anniversary, this year also represents the 100th anniversary of the macromolecular hypothesis, first publicly presented by Hermann Staudinger in a talk before the Swiss Chemical Society[2] in 1917. Staudinger worked for years to overcome considerable opposition to the concept that polymers are long chains of smaller molecules connected by covalent bonds, as opposed to some unspecified kind of physically associated, colloidal structures.

By World War II, the macromolecular nature of polymers was generally accepted, and commercial examples such as nylon were widely hailed. The need for synthetic rubber during and after the war helped the polymer industry expand enormously. Based on today's commercial demand, the industry will continue to experience strong growth.

Although commodity plastics will likely remain the largest component of the market for the foreseeable future, the incorporation of advanced polymers into higher-value applications is more exciting. Examples include coatings on drug-eluting stents, patterning materials for nanometer-scale lithography, and fuel-efficient aircraft—the Boeing 787 Dreamliner is 80% plastic composite by volume. Even polyethylene, the world's largest-volume, least expensive, and chemically simplest polymer, can be processed into fibers 10 times as strong as steel; they are used in bulletproof vests, cables to anchor floating windmills, and other applications. Scientific advances in polymers open the door to even more interesting questions that involve molecular behavior and collective properties. So if someone suggests that you direct your future to plastics, pay attention!

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LETTERS

Trapping molecules for quantum chemistry

The Search and Discovery piece by Ashley Smart in the April 2017 issue of PHYSICS TODAY (page 18) reported the excellent work on magnetic stopping and trapping of methyl radicals by the group of Takamasa Momose (University of British Columbia). I am writing to provide a different perspective on the field than what was conveyed by the author. The very first sentence of Smart's article brings up a whole discussion: "By and large, physicists have succeeded in their quest to tame the atom."

The past few decades have seen re-

markable advances in the ability to control and cool atoms in the gas phase. Those advances have been enabled by laser-cooling, which produces ultracold atomic gases. The atoms are then further cooled by evaporation to create quantum degenerate gases. However, those methods are far from ideal, even for atoms.

Laser cooling is not a general method. Due to the requirements of a cycling transition and available lasers, it works on only a small set of elements in the periodic table. Evaporative cooling requires the right balance between elastic and inelastic collisions, again severely limiting generality. Furthermore, evaporative cooling leads to a large loss of atoms. For the alkalis, the optimum cases for laser cooling and evaporative cooling, the flux of ultracold atoms has been limited by optical density to around 10^9 atoms per second.

It is natural to ask whether one can invent new methods that work on most elements and that break the current limit on flux. Such a development would open many new possibilities for fundamental science and for real-life applications. The challenges and limitations have motivated several groups to explore alternative approaches. One method is buffer-gas cooling, pioneered by John Doyle at Harvard University.[1] A different approach was developed independently and in parallel by Frédéric Merkt and his group at ETH Zürich and by my group at the University of Texas at Austin: magnetic stopping and trapping of paramagnetic atoms in a supersonic beam.[2,3] That work was summarized in an invited review article I wrote for *Science*.[4] Since then, many new developments have continued to advance the field.

Now that the first sentence of the Search and Discovery piece is out of the way, I can discuss the rest—in particular, the motivation of studying quantum chemistry and the question of whether one actually needs to trap molecules. The goal of studying chemical reactions at ultralow temperatures is to observe unique quantum pathways that can dominate the reaction dynamics. Until recently it has been an elusive goal. Stopping and trapping molecules, either by electrostatic or magnetic forces, has produced a phase-space density that is too low for the study of chemical reactions. Molecules at much higher phase-space density can be produced by starting with Bose–Einstein condensates and "making" molecules with lasers. However, those experiments have so far been limited to alkali chemistry.

Work by the Narevicius group at the Weizmann Institute of Science in Israel provided a major breakthrough in quantum chemistry without the need for stopping and trapping. Their approach relies on the merging of two supersonic beams by magnetically deflecting one of them.[5] The copropagating beams have controllable collision energies down to temperatures of several millikelvin. The resulting chemical reactions, observed as a function of energy, reveal striking quantum resonances in the reaction dynamics. That work is continuing, and it demonstrates the power of merged beams, which do not require trapping and cooling. To study slower chemical reactions, trapping at high phase-space density is necessary. New ideas and work along those lines are in progress and will hopefully prove successful.

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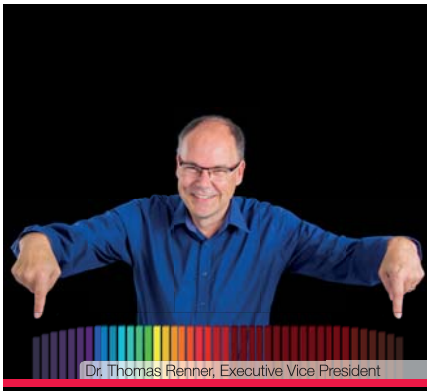
Heisenberg letters show courage in horrific times

Silvan Schweber's review of *My Dear Li: Correspondence 1937–1946* (PHYSICS TODAY, July 2017, page 59) by Werner Heisenberg and Elisabeth Heisenberg is a poignant commentary—sadly, at the end of his life. It is poignant because it bespeaks the impossibility of reconciling any life lived in freedom of expression and governed by law with the one Werner Heisenberg chose in Germany, against the odds, despite being deprived of such liberty. Is it the right moral choice to continue living in one's country under repressive circumstances? What considerations play into such a decision?

The correspondence in the book



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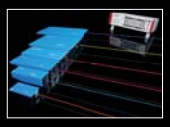
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